SOFIA-FORCAST Imaging Survey toward the Galactic Giant HII Regions: II. M17

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Why massive stars are important?

Reason #1 - Chemical Input

Graphic created by Jennifer Johnson

Astronomical Image Credits: ESA/NASA/AASNova
Why massive stars are important?

Reason #2 - Energetic feedbacks

The enormous massive star feedback can be a critical source to form and maintain the shapes of the environmental GMCs!
Why massive stars are important?

Reason #3 - Seeds of SMBHs
Evolutionary sequence of Massive stars and star clusters
(Beuther et al. 2007)

Cores to stars
→ High-mass starless cores (HMSCs)
→ High-mass cores harboring accreting low/intermediate mass protostar(s) destined to become a high-mass star(s)
→ High-mass protostellar objects (HMPOs)
→ Final stars

Clumps to clusters
→ Massive starless clumps
→ Protoclusters
→ Stellar clusters

Two simple stages
- Infrared Quiescent (Infrared Dark Clouds)
- Infrared Bright (GHII regions)
Giant HII (GHII) regions are...

- well known active massive star forming regions.

- bright across almost all wavelengths.

- only IR bright objects you can recognize easily from external galaxies.

Thus, it is important to study Galactic GHII regions to understand star formation even in external galaxies.

- W51A : one of the most massive Galactic GHII regions (Lim & De Buizer 2019)

- M17 : one of the closest GHII regions in from Sun (Lim, De Buizer & Radomski 2020)
Why we need SOFIA?

Angular resolutions of Space/Airborne Telescopes

IRAS ~ 1x4 arcmin
MSX ~ 18 arcsec
Spitzer-MIPS ~ 6 arcsec
SOFIA-FORCAST ~ 3 arcsec
Result 1.
We have found an embedded population of MYSOs.
MYSO Candidates

SOFIA 37µm

Lim ea 2020
MYSO Candidates

![Graphs and images related to MYSO candidates.](image)

Lim ea 2020
7 / 16 SOFIA sub-components and point sources are under MYSO criteria.

4 / 7 MYSO are first defined (suggested) in this study.

Note that we found 41/47 MYSOs from W51A. The distance may matter.

20 & 37 µm data points are necessary to achieve the envelop SEDs.
Result 2.
The entire M17 cloud does not seem to be coeval.
Proto-cluster Evolution

Virial analysis

\[ \alpha_{\text{vir}} = \frac{2T}{|W|} \approx \frac{5\sigma^2 R}{GM} \]

(Bertoldi & McKee 1992)

Higher \( \alpha_{\text{vir}} \) may indicate the later clump evolutionary stages (i.e. more internal feedback makes higher kinetic energy).

\[ \frac{L_{\text{bol}}}{M_{\text{dust}}} \]

Higher L/M might indicate older clump due to more formed stars and less dust mass (used to make stars).
Proto-cluster Evolution

$\alpha_{\text{vir}}$ vs. L/M

Virial Parameter ($\alpha_{\text{vir}}$)

L / M ($L_\odot / M_\odot$)

W51A
M17
Triple
Cavity
M17N
M17S

SOFIA 37\mu m
As of W51A case, M17 also shows various evolutionary stages of porto-cluster thus structures in M17 are not coeval.

- The Cavity region is a massive stellar clusters (including NGC6618) and shows highest $\alpha_{\text{vir}}$ and L/M values.
- M17N seems to be older than M17S.
- Both M17N and M17S seem to be far from the main trend. We assume this is due to the PDR contamination.
Result 3.
We found possible 20\(\mu\)m contamination by [SIII] line.
20μm images contaminated by [SIII]

Why so serious?

Blue - 20μm, Green - 37μm, Red - 70μm, White - 3.6μm
We have been fortunate enough to find ISO observation toward this region.

Blue - 20μm, Green - 37μm, Red - 70μm, White - 3.6μm
20μm images contaminated by [SIII]

Lim ea 2020

Green - 20μm, Red - 37μm
20µm images contaminated by [SIII]

- 20µm images are quite unique comparing to other wavelength regimes.

- The ISO archival data show the significant enhancement of the [SIII] line at PDR regions.

- 20µm imaging would be a good tracer for ionized regions of Galaxy.
Summary

- FORCAST 20 & 37μm imaging survey toward Galactic GHII regions is on-going and you now see the second results!

- The SOFIA data revealed a previously hidden population of MYSOs and gave us better understanding the physical nature of several already known sources.

- We find many MYSO candidates identified by other studies are not actually MYSOs.

- Independent evolutionary analyses show the structures in M17 are not coeval.

- FORCAST 20μm imaging is possibly a good tracer for ionized regions ([SIII] line).
Star Cluster Formation in Orion A

(Investigating how cloud-cloud collision important as a massive star cluster forming mechanism.)
CARMA-NRO Orion survey (Kong ea 2018)

- angular resolution ~5”.

- The closest separation among YSOs in IN-SYNC project is ~6”

- We now can compare the velocity difference and gas column density to the properties of individual YSOs!
Result 1. $v_{\text{CO}}$ vs. $v_{\text{YSO}}$ of Orion A cloud

- Older YSOs have gotten less associated with the dense gas structure.
- Supporting Cloud-Cloud Collision scenario?

Simulations are based on Wu et al. 2017 (Lim et al. 2020 PASJ)
Result 2. $v_{\text{CO}}$ vs. $v_{\text{YSO}}$ of Star Clusters

- ONC-OMC1, OMC4 and L1641N clusters seem to qualitatively agree with Clouc-Cloud Collision scenario.
- OMC2 and OMC3 do not agree with either scenarios while NGC1999 favors non-colliding.
Result 3. $^{13}$CO vs. [CII]

- $^{13}$CO and [CII] show spatial and velocity offsets at several locations (local, i.e. individual pixels).
- Supporting Cloud-Cloud Collision scenario?

(Lim ea 2020 PASJ)
Additional Summary

- We utilized three independent survey data to Orion A cloud to trace the history of star cluster formation, especially tested cloud-cloud collision scenario.

- The $^{13}$CO vs. YSO analysis shows the older YSO the less the kinematic association between dense gas structure.

- The individual star clusters may favor cloud-cloud collision, especially at the northern part of Orion A.

- The $^{13}$CO vs. [CII] of northern part of Orion A shows also slight favoring of cloud-cloud collision scenario.

- Further observational analyses with more complete simulations would confirm or refute the cloud-cloud collision as an important mechanism for star cluster formation in Orion A cloud.